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ISOMETRIC MUSCLE FORCE AND ANTHROPOMETRIC VALUES IN NORMAL CHILDREN AGED BETWEEN 3.5 AND 15 YEARS

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ABSTRACT. Isometric muscle force was measured in 217 normal children aged 3.5–15 years. The standard error of a single determination made by the same observer was ca. 9 % of the muscle force. When two measurements were made by different observers the standard error of the difference was estimated at ca. 17 %. Reference values for isometric force are given for boys and girls separately. With regard to 7 of the 10 muscle groups tested the force was significantly greater in boys than in girls as early as at ca. 10 years of age. Age and weight were the most important predictors of muscle force.

Key words: muscle strength, muscle force, anthropometry.

Assessment of neuro-muscular function is part of a routine neurological examination. It will be more accurate and clinically meaningful if it is based on objective measurements and not merely on clinical estimations. This is especially true when evaluating a treatment programme or the progress of a pathological process or the effect of training. A method for measuring muscle force for routine clinical use should be simple to perform, it should give reproducible results under standardized conditions, and reference values should be available.

The aim of the present study was to establish reference values for muscle force in normal children of different ages, using a method that meets the above requirements. Reference values for muscle force for 2 muscle groups measured with a dynamometer similar or identical to that used in the present study have been reported by Scott et al. (14), and for 6 muscle groups by Hosking et al. (6). Reference values are now presented for 10 different muscle groups, the results for boys and girls being given separately. The predictive value of age, weight, and height was also investigated.

MATERIAL AND METHODS

The study population comprised 219 school and pre-school children, 104 girls and 115 boys, aged 3.5–15 years. All school-children were tested except for a boy with hereditary polyneuropathy and another with gross obesity; one boy aged 7 years refused to participate. All children were interviewed about their health in accordance with a standard questionnaire. None had a history of cardiac disease or a recent history of severe respiratory symptoms. All participated in the school's or day nursery's ordinary physical training programme. Right- or left-handedness was noted. When skeletal trauma had occurred within the last two years the affected extremity was not subjected to measurements. Most measurements were performed by one of the authors (E.B.), aided by a laboratory technician. There was no significantly in getting the children to cooperate, and most of them found the investigation interesting.

To assess the reproducibility of the method a whole school class of children aged 13–13.5 years was tested twice with an interval of 3 months; ten 6-year-olds were tested twice by the same investigator with an interval of 3–14 days; and 11 other children (age 6.5–14 years) were tested by four different investigators within one week. The coefficients of variation were estimated.

During the test the children were urged to force their muscles to maximum capacity. Informed consent was obtained from both the children and their parents.

Anthropometry

Age, body-weight, and height were recorded. The age was given to the nearest 6 months; body-weight was measured with an accuracy of ±0.1 kg, and height with an accuracy of ±0.5 cm.

Muscle force

Isometric force was measured with a portable electronic dynamometer (Myometer, Penny and Giles Transducers Ltd., Dorset, England). The instrument consists of a hand-held force transducer, an electronic display, and an amplifier unit (Fig. 1). The peak force value is expressed in kg. The operating range is 0–35 kg and the accuracy ±0.3 kg (11). The dynamometer was calibrated with known weights placed on the transducer plate. The muscle groups tested and the sites of application of resistance are shown in Table I. The same type of fixation as that used by Janda (7) was employed. 10 muscle groups on each side were each measured three times with an interval of 2–5 min and the highest value was used. The breaking force technique was employed, an isometric contraction of at least 2–3 s being required. The whole investigation took 35–40 min.

Table I. *Muscle groups tested, sites of fixation and application of resistance, and the posture of the child in the test situation*

Muscle group	Posture Joint angle	Immobilization	Application of resistance
Elbow flexors	Sitting 90°	Posterior aspect of upper arm just above the elbow, keeping the joint free	Flexor surface of forearm, just above the wrist
Knee extensors	Sitting 0°	Posterior aspect of thigh, just above the knee	Anterior aspect of lower leg, just above the malleoli
Ankle dorsiflexors	Sitting 0°	Posterior aspect of the leg just above the ankle, avoiding pressure on the tibialis anterior	Dorsal aspect of the foot proximal to the metatarsophalangeal joint
Shoulder abductors	Sitting neutral position, 90°	Over the middle third of the shoulder, keeping the joint free. Shoulder elevation is prevented	Over the distal third of the arm, just above the lateral epicondyle
Hip flexors	Supine 90°	The pelvis is held at the iliac crests	Anterior aspect of the distal third of the thigh
Hip abductors	Supine 30°	The pelvis is held at the iliac crests	Lateral aspect of the distal third of the thigh
Wrist dorsiflexors	Supine 70°	Distal third of the dorsal aspect of the forearm	Dorsum of the hand
Knee flexors	Prone 90°	The pelvis is pressed against the couch	Posterior aspect of the distal third of the leg, just above the ankle
Hip extensors	Prone 30°	The pelvis is pressed against the couch	Dorsal aspect of the distal third of the thigh
Elbow extensors	Prone, with arm supported on the couch and forearm hanging down 90°	The shoulder is pressed against the couch; the lower third of the upper arm is grasped from beneath	Dorsal aspect of the distal third of the forearm

In the ten 6-year-olds who were tested twice, only the elbow flexors and the dorsiflexors of the ankle were examined. In the children tested by four different investigators the elbow flexors and extensors, hip flexors, knee extensors, and dorsiflexors of the ankle were tested. Two of the investigators had had previous experience of the method.

Statistical evaluation

Mean values between groups were compared by Student's two-tailed *t*-test. Student's *t*-test for paired samples was used to compare the dominant and non-dominant sides and to evaluate the results in the children who were tested twice. When constructing diagrams of the lower fifth percentile of the force in various muscles, it was necessary to choose a set of variables to use in the prediction of force. The predictive value of different combinations of the factors age, weight, and height was studied by linear regression analysis.

In order to estimate the size of measurement errors, test-retest values for the twice-tested 6-year-olds and the school-class of 13–13.5-year-olds were analysed. The standard deviation of the differences in recordings between the two tests, when divided by $\sqrt{2}$, gives an

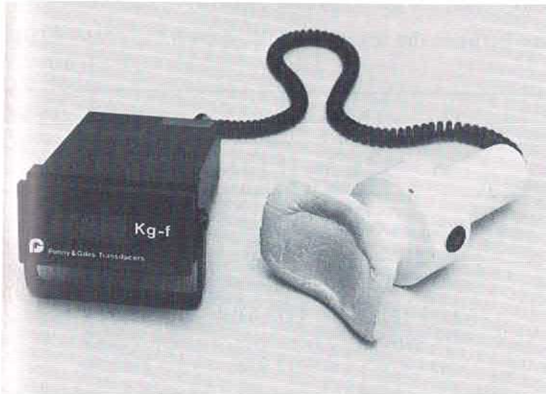

Fig. 1. Myometer (Penny & Giles Transducers Limited, England).

estimate of the standard error of a single measurement. Such standard errors are expressed in per cent of the average measurement size in order to obtain a coefficient of variation of measurement error.

The standard errors of measurement refer to a single investigator. Similar analysis of repeated measurements made by the four investigators on children of varying ages was carried out by two-way analysis of variance. The average values obtained for the different investigators were also analysed to detect any systematic differences between them.

RESULTS

Anthropometric values and muscle force

The mean values for height and body weight and the number of subjects in different age groups are presented in Table II, and the mean values for force in the different muscles at different ages are shown in Table III. The values for the non-dominant side are given. The absolute force values were significantly greater on the dominant than the non-dominant side for the elbow flexors and hand dorsiflexors in both girls and boys. On the dominant side the force of the knee flexors was greater in the girls, and that in the knee extensors, dorsiflexors of the ankle, and hip extensors was greater in the boys.

Force values exceeding 350 N were recorded in 5 of the boys and 4 of the girls for the dorsiflexors of the ankle and the knee extensors, and in 8 boys and 3 girls for the abductors and/or the flexors, and/or the extensors of the hip.

The predictive value of anthropometric values

In each child 10 muscle groups on each side were tested; the force values for boys and girls were analysed separately. When only one variable (age, weight, or height) was used for prediction of muscle force, none of the variables was significantly superior to any of the others. When using two independent variables in the linear regression model, age and weight gave the best regression in 25 of the 40 combinations (two sexes, two sides and 10 muscle groups). The use of three variables (age, weight, and height) compared with two (age and weight) increased the prediction values significantly in only 5 instances of the total of 40.

Predicted lower fifth percentile limits for measured muscle force for both sexes using age and weight as variables are presented in Fig. 2. The tables are restricted to three categories of weights (normal and normal ±2 SD) in accordance with the weight tables of Karlberg et al. (9).

Reproducibility of tests

In the 24 children tested twice with an interval of 3 months, the estimated coefficient of variation of measurement error varied in the 10 muscle groups from 6% (elbow flexors) to 16% (hip flexors).

Table II. *Weights and heights (mean ± SD) of girls (g) and boys (b) of different ages*
n=number of subjects

		Age, yrs					
		3.5–5	5.5–7	7.5–9	9.5–11	11.5–13	13.5–15
n	g	9	18	12	19	14	32
n	b	13	23	13	14	18	32
Weight (kg)	g	18.4±2.4	20.9±2.8	28.3±3.5	32.3±5.4	41.7±11.4	52.4±8.5
	b	18.0±2.5	22.1±2.9	26.6±3.6	31.3±3.9	42.2±4.9	53.6±10.5
Height (cm)	g	108.0±4.4	118.7±6.5	132.1±3.5	142.7±5.9	152.7±7.6	162.5±5.2
	b	108.7±5.0	120.5±5.1	129.1±4.3	140.4±6.6	154.4±5.6	166.8±9.0

Table III. *Muscle force in newtons (N) on the non-dominant side, for girls (g) and boys (b) of different ages*

Values are given as mean ± SD. *t*-test of the difference in force between the sexes: $p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$. NS=not significant

		Age (yrs)					
		3.5–5	5.5–7	7.5–9	9.5–11	11.5–13	13.5–15
Elbow flexors	g	77±16	105±21	112±17	129±26	152±32	192±24
		NS	NS	NS	***	*	***
	b	77±23	108±21	124±16	164±27	177±29	240±47
Knee extensors	g	82±14	119±24	136±32	181±46	197±63	282±54
		NS	NS	NS	NS	NS	NS
	b	91±23	120±18	139±20	198±42	211±34	296±59
Ankle dorsiflexors	g	85±22	124±33	146±43	184±40	217±60	290±49
		NS	NS	NS	NS	NS	NS
	b	100±20	130±21	148±29	204±49	231±60	302±45
Shoulder abductors	g	53±16	84±20	94±16	99±22	130±32	155±28
		NS	NS	**	**	NS	**
	b	62±17	88±15	117±20	125±23	147±30	186±45
Hip flexors	g	71±20	112±25	141±33	154±28	198±48	260±50
		NS	**	NS	**	*	NS
	b	86±25	132±26	168±48	197±45	234±37	284±56
Hip abductors	g	98±8	150±39	189±54	188±26	226±50	260±50
		NS	NS	NS	NS	NS	NS
	b	104±20	155±38	182±45	204±47	233±53	265±49
Wrist dorsiflexors	g	37±10	68±14	80±17	95±21	127±30	167±33
		NS	NS	NS	***	**	*
	b	44±9	73±22	89±20	128±26	154±26	189±41
Knee flexors	g	53±18	85±22	118±19	125±26	155±35	203±42
		NS	NS	NS	**	NS	*
	b	58±22	99±23	134±34	157±32	176±29	230±62
Hip extensors	g	76±18	124±34	157±19	174±30	226±61	267±50
		NS	NS	NS	**	NS	NS
	b	80±22	131±46	170±36	210±48	226±25	277±45
Elbow extensors	g	53±14	80±11	97±15	109±24	122±26	158±31
		NS	NS	NS	**	NS	**
	b	50±14	88±18	108±22	139±26	142±29	187±51

Table IV. *Components of measurement error expressed in per cent of measurement size*

	Estimated difference between two observers	Estimated standard error of measurement for a single observer	Estimated standard error of measurement of change: Repeated measurements by the same observer	Estimated standard error of measurement of change: Repeated measurements by different observers
Elbow flexors	11.7	8.6	12.2	16.9
Knee extensors	10.4	8.1	11.5	15.5
Ankle dorsiflexors	10.8	8.7	12.3	16.4
Hip flexors	13.5	11.0	15.6	20.6
Elbow extensors	6.4	8.2	11.7	13.3

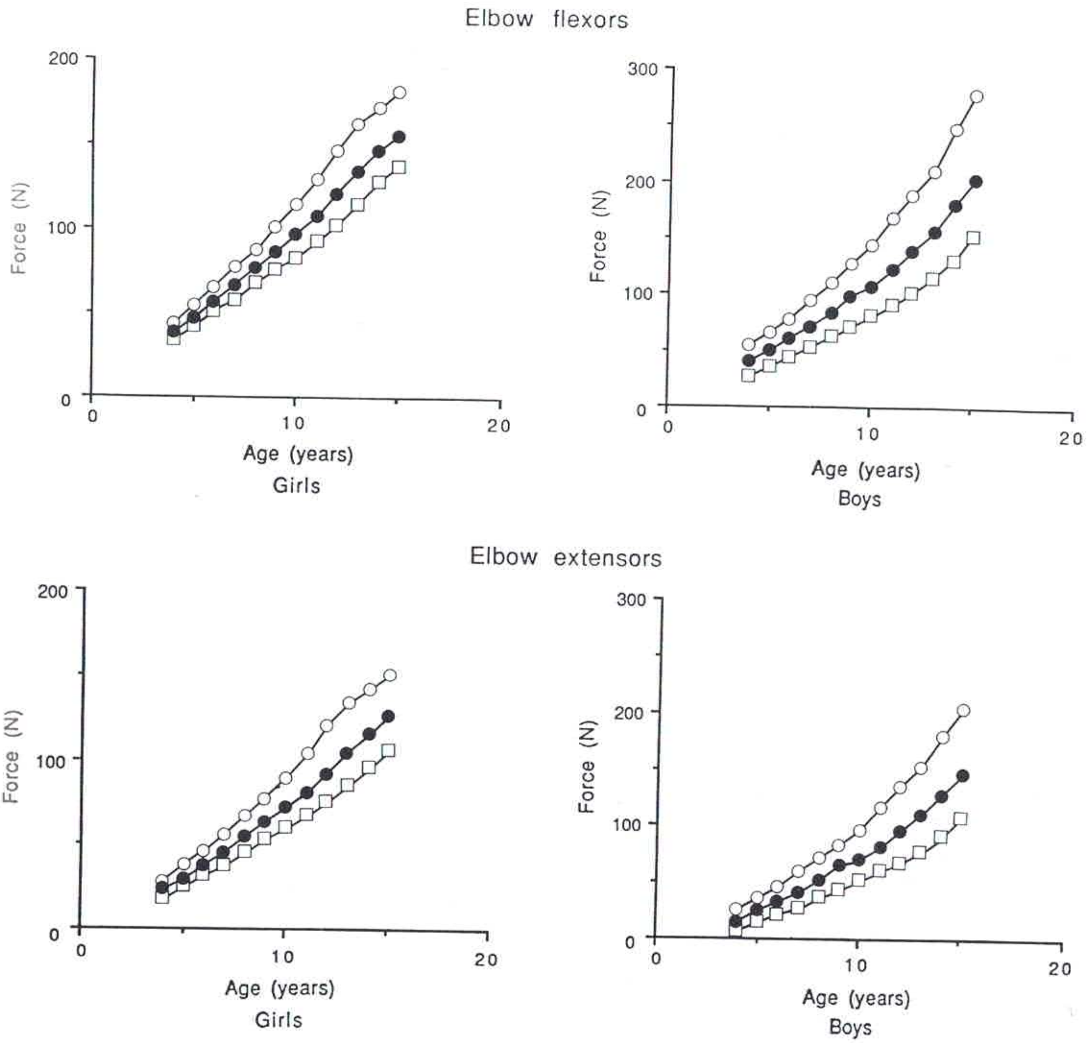

Fig. 2a. Reference values expressed as the lower 5th percentile for isometric muscle force. ○, children of average weight +2 SD; ●, children of average weight; □, children of average weight −2 SD.

In the 6-year-olds, the coefficient of variation of measurement error was estimated to be 6% for the ankle dorsiflexors and 12% for the elbow flexors.

In the children tested four times by four different investigators, the coefficients of variation of measurement error varied between 8% and 11%. There were significant differences between investigator averages in all measurements except for those concerning the elbow flexors. However, no investigator had consistently higher or lower measured values than any of the others. The observed difference between measurements on the same child performed by two different investigators was ca. 15 N, except in the case of the elbow flexors for which it was 5 N. This corresponds to a standard error of approximately 17% in a measurement of change when an individual is measured on two occasions by different observers. Components of measurement error are given in Table IV.

DISCUSSION

The present study comprises a series larger than any previously reported, and reference values are given for a greater number of muscle groups (3, 6).

The simple dynamometer employed can be used

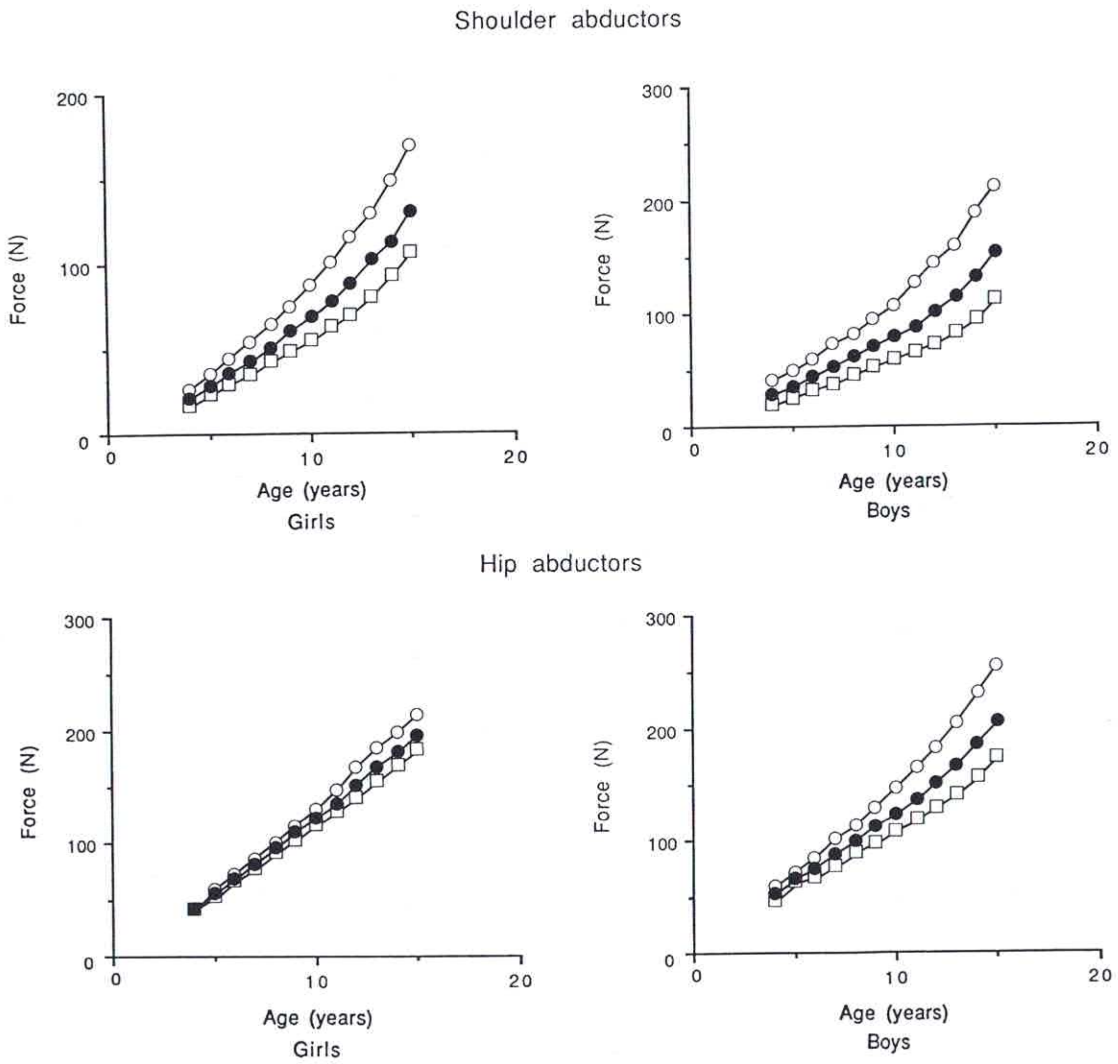

Fig. 2b. Reference values expressed as the lower 5th percentile for isometric muscle force. ○, children of average weight +2 SD; ●, children of average weight; □, children of average weight −2 SD.

for quantitative measurements. Previous investigations on smaller groups and in boys with progressive muscular dystrophy have shown that this and similar instruments give reproducible results (3, 6, 14). Standardization of the test situation is important. The mode of fixation and the sites of application of the external load must be kept identical. The usefulness of the method is limited, because the upper limit of the range of the myometer is ca. 350 N, and some teenagers can exert a force greater than this with certain muscle groups. An extension of the measuring range would be helpful, but the limiting factor might then be the capacity of the investigator to exert a pressure exceeding 350 N (2). Values above 350 N are less reliable than values below 350 N with this instrument, so the mean values obtained for these age and muscle groups might be uncertain.

Children under 3.5 years cannot be made to cooperate in measurements of this kind. Further, the youngest age group tested (3.5–5 years) had difficulty in activating the muscle groups governing hip function, in contrast to older children. The method can also be used in adults with impaired muscle force.

Differences in force emerged between the domi-

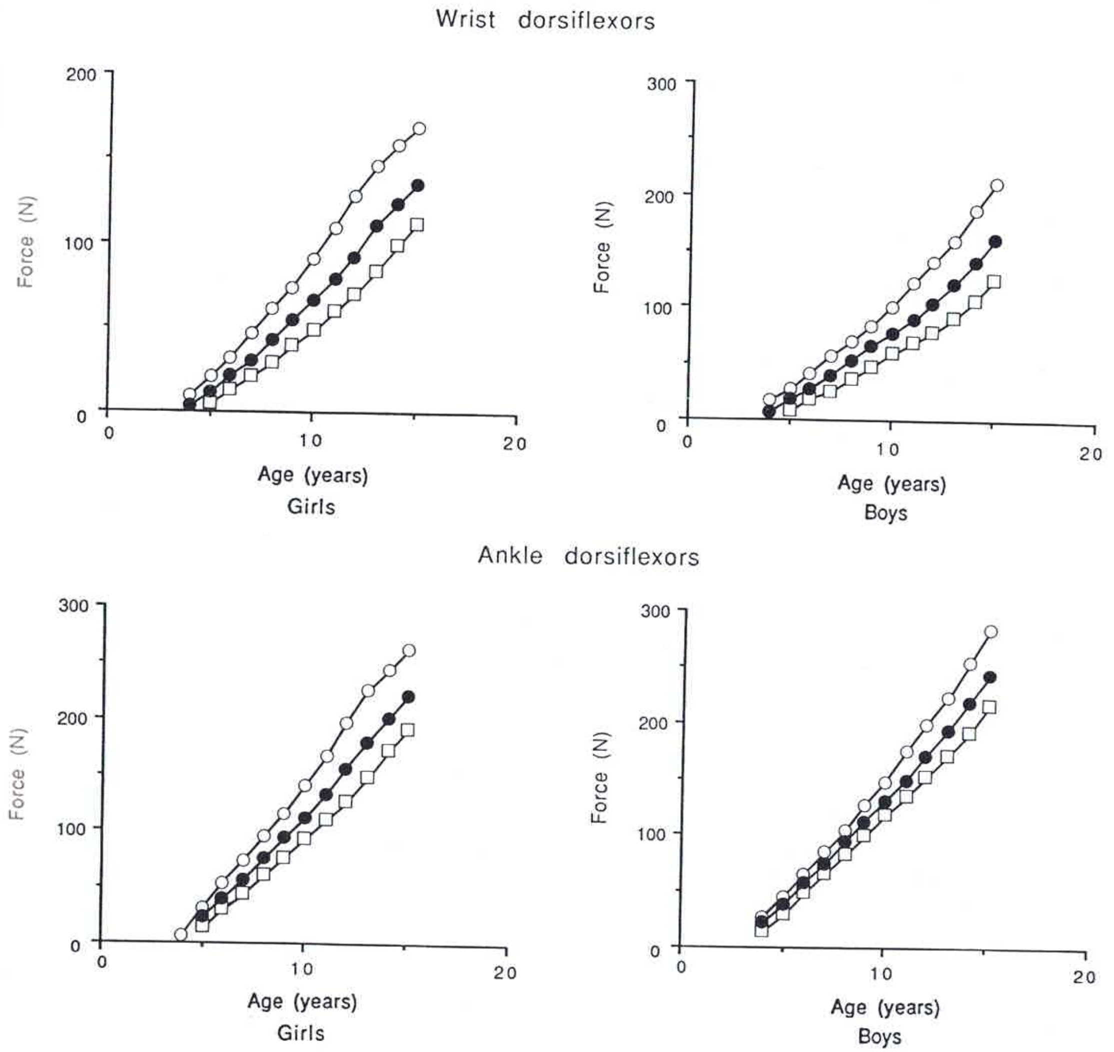

Fig. 2c. Reference values expressed as the lower 5th percentile for isometric muscle force. ○, children of average weight +2 SD; ●, children of average weight; □, children of average weight −2 SD.

nant and non-dominant sides. In both boys and girls the elbow flexors and dorsiflexors of the wrist were stronger on the dominant side. In girls the knee flexors and in boys the knee extensors, dorsiflexors of the ankle, and hip extensors were stronger on the dominant side. We recommend that repeated tests of muscle force always be performed on the same side of the body.

The correlations between anthropometric measurements and maximum voluntary muscle forces are of practical importance. The combination age and body weight seems to be the best predictor of muscle force. Measures including arm and forearm circumferences, shoulder width, radial or humeral linkage, wrist width, and thickness or other hand measurements, have not proved to have predictive value (5, 8). Adding height to age and weight does not significantly improve prediction. The heights and weights in our study population are very close to the standard curves for normal Swedish children of similar age (+0.5 SD to −0.25 SD) (9).

There was no significant sex difference with regard to muscle force in the youngest children. This conforms with the findings of Hosking et al. (6). Others maintain that the difference in force between the sexes appears or is accentuated in puber-

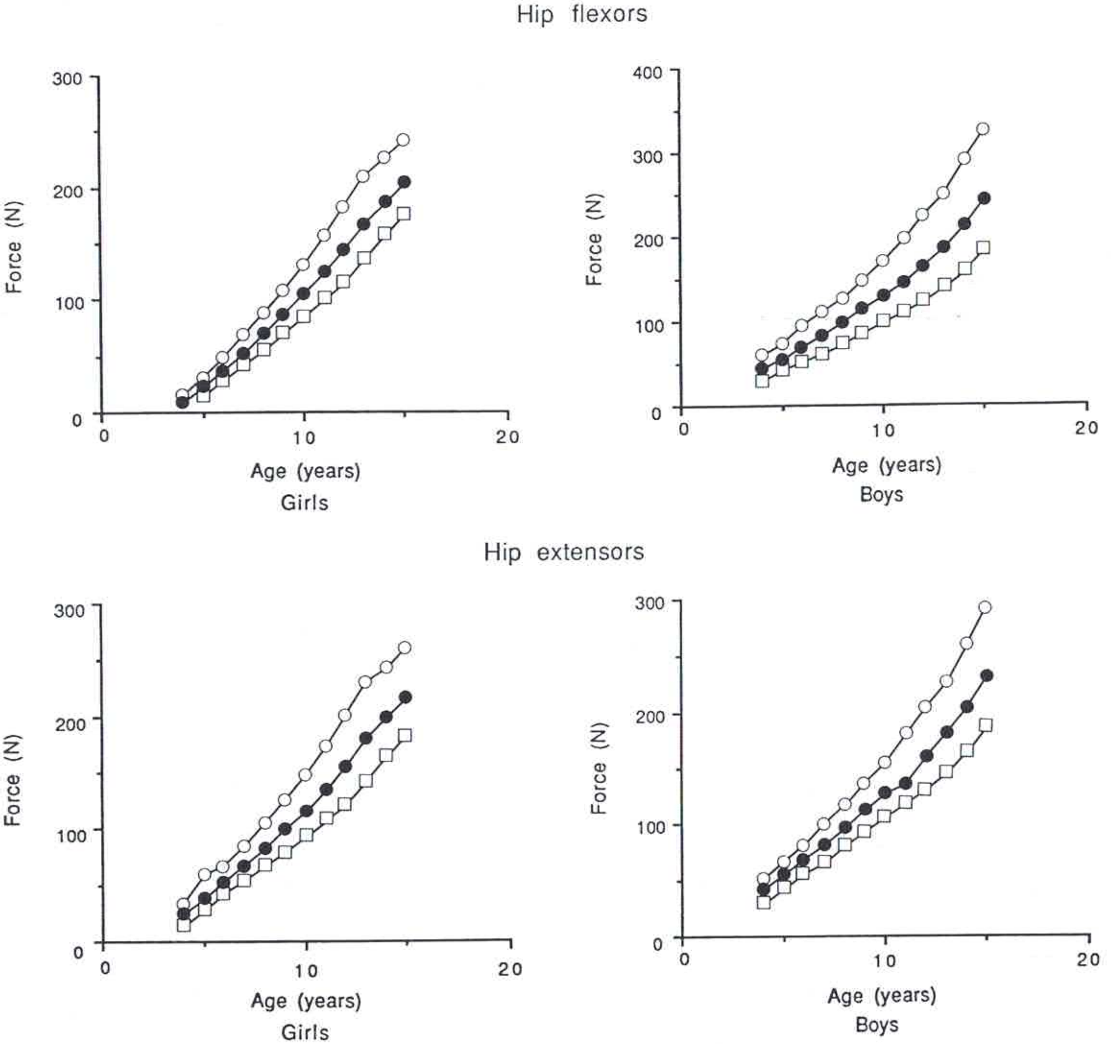

Fig. 2d. Reference values expressed as the lower 5th percentile for isometric muscle force. ○, children of average weight +2 SD; ●, children of average weight; □, children of average weight −2 SD.

ty (1, 8, 15), and that some of the differences can be related to differences in height and weight (8). In the present study muscle force was already significantly greater in the boys aged 5.5–7 years and 7.5–9 years with regard to 1 of the 10 muscle groups tested, and in boys aged 9.5–11 with regard to 7 muscle groups. In the 11.5- to 13-year-olds a difference was shown in 3 muscle groups, and among the oldest children the boys were stronger with regard to 5 of the 10 muscle goups (Table III). The force in teh knee extensors, dorsiflexors of the ankle, and hip abductors did not differ signficantly between boys and girls at any age.

The length of the lever arms could differ slightly between boys and girls, however; this would influence the results. Our results can be compared with those of Rarick et al. (12); they found that at 7 years boys were already stronger than girls, and speculated that this sex difference could be due to "the impact of cultural influences on the role model for the sexes (13).

In general, the total muscle force in adult women is about two-thirds of that in men, but when correlated to body weight the difference is eliminated (10).

It is difficult to compare the reference values now

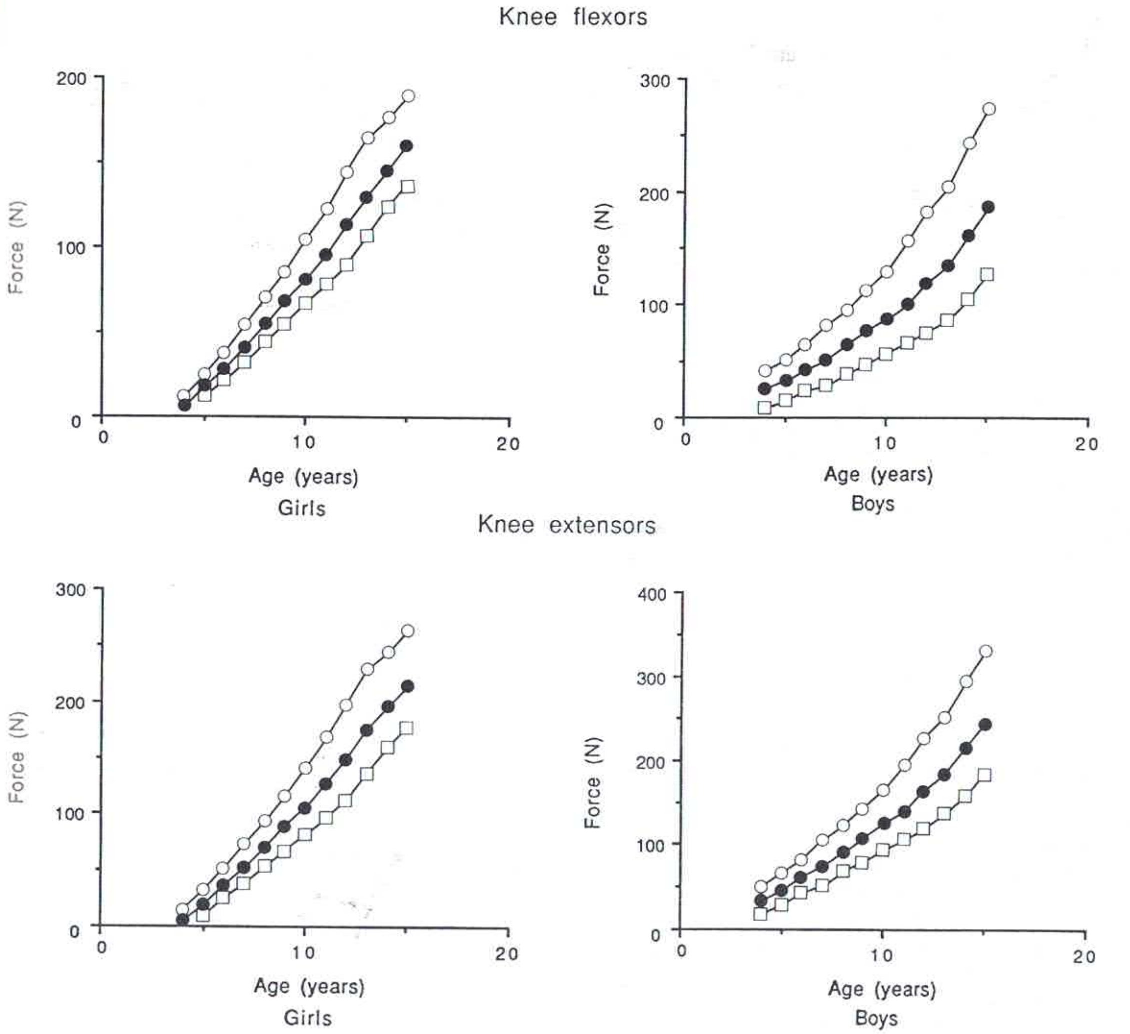

Fig. 2e. Reference values expressed as the lower 5th percentile for isometric muscle force. ○, children of average weight +2 SD; ●, children of average weight; □, children of average weight −2 SD.

presented with those of Hosking et al. (6). Hosking et al. related the developed force to either height or weight; our force values are related to age and weight combined or to age alone. The most striking difference in muscle force between the Swedish and English children is that the force values in the dorsiflexors of the ankle were substantially lower in the English group. The difference probably reflects some methodological discrepancy.

The reproducibility is acceptable for a method to be used in clinical practice. The standard error of a single determination made by the same observer is roughly 9% of the force. When studying change, the same individual will be measured twice, and the standard error of the measure of change will be ca. $\sqrt{9^2+9^2}$, or 13% provided that both measurements are performed by the same observer. Differences between observers seem to be about 11%. Consequently, a measure of change will have a standard error of approximately $\sqrt{9^2+9^2+11^2}$, or 17%, if the two measurements involved are made by different observers. These calculations are rough, but they give some idea of the general size of the errors involved.

The absolute values for the measured muscle force reflect the combined effect of several neural and muscular functions in a standardized bio-mechanical situation. An estimation of the motivation of the child, the child's cooperation, and his or her ability to activate the motor units tested should always be added to the test protocol.

Complete testing of the 10 muscle groups in the present study, on both dominant and non-dominant sides, takes about 30–40 min to perform. In clinical practice the number of muscle groups can be reduced, and the time for measuring muscle force consequently shortened.

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